Stratified Flow over Rough Topography: Internal Wave Excitation and Near-Source Interactions

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LONG-TERM GOAL

My long-term goal is to better understand the ways in which oceanic mixing is regulated by internal wave dynamics, focusing in particular on sites characterized by intense mixing. A second goal is to improve, validate, and make available numerical models for direct simulation of wave dynamics in the vicinity of irregular topography.

OBJECTIVES

The objective of this study is to better understand the linkage between internal wave generation, near boundary mixing and local wave-wave energy transfers induced by stratified flow over variable topography.

APPROACH

Two problems are being addressed in this study. The first is motivated by the observations of Gregg and Lien off the Northern California coast in which a beam of intense turbulence was found to coincide with the path of energy propagation for M_2 internal tides generated at the shelf/slope break. In this study, I take a numerical approach and directly simulate the response of a stratified fluid to oscillatory forcing in a shelf/slope geometry. The simulations are based on non-hydrostatic dynamics using a boundary-fitting grid with spatially variable resolution. The objective is to resolve generation of internal tides as well as their subsequent nonlinear evolution as they propagate.

The second problem focuses on the near field nonlinear interactions within a broad-banded internal wave field excited as both steady and oscillatory mean currents flow over an undulating bottom characterized by a range of spatial scales.

Both studies require the simulation capability to resolve near boundary interactions in the non-hydrostatic limit. The simulations are being conducted with S-FIT (Stratified Flow Interacting with Topography) [Winters et al 2000] developed previously under ONR support.

WORK COMPLETED

Preliminary simulations have been done for both study problems. Feasibility and formulation issues have largely been addressed.

A significant effort has gone into parallelizing the algorithm using MPI (Message Passing Interface) allowing the code to be used on sequential machines, clusters of workstations or parallel supercomputers.

To increase speed, parallelization and flexibility in problem formulation, the pressure solver has been reformulated and replaced.

In conjunction with this effort, algorithm and code documentation has been developed. This has resulted in a 100-page manual describing the mathematics, the numerical algorithms and the implementation on parallel machines in detail. It is hoped that this document will facilitate use by others for problems involving topographic effects in stratified fluids.

RESULTS

Scientific results for FY00 are preliminary and primarily pertain to the excitation of internal tides at a shelf/slope break. Preliminary, idealized simulations have been performed in which an oscillating on/off-shore flow sweeps over a slope/shelf topography. Initially, the stratification is uniform throughout the fluid. Our immediate objective was to excite beams of internal tides as predicted by linear theory and to look at non-linearities that might lead to enhanced, near-source mixing offshore of the break as observed near Monterey. Our initial simulations however, were not particularly interesting offshore of the break. No significant nonlinear interactions were observed, even for unrealistically strong tidal forcing.

Rather, the simulations very nicely captured a periodic excitation of highly nonlinear, solibores (bore-like, solitary waves) propagating onshore. The propagation of these waves is alternately retarded (or reversed) and accelerated by the ambient tidal flow. Because the bores have intrinsic propagation speeds onshore, they result in a net flux of dense water up onto the shelf. This in turn creates lateral density gradients in the upper water column.

Figure 1 shows the time evolution of a single isopycnal (the flow is uniformly stratified) originally located at shelf depth taken from a single xz plane. The dashed lines at the right show the net advance of the solibore over a tidal cycle.

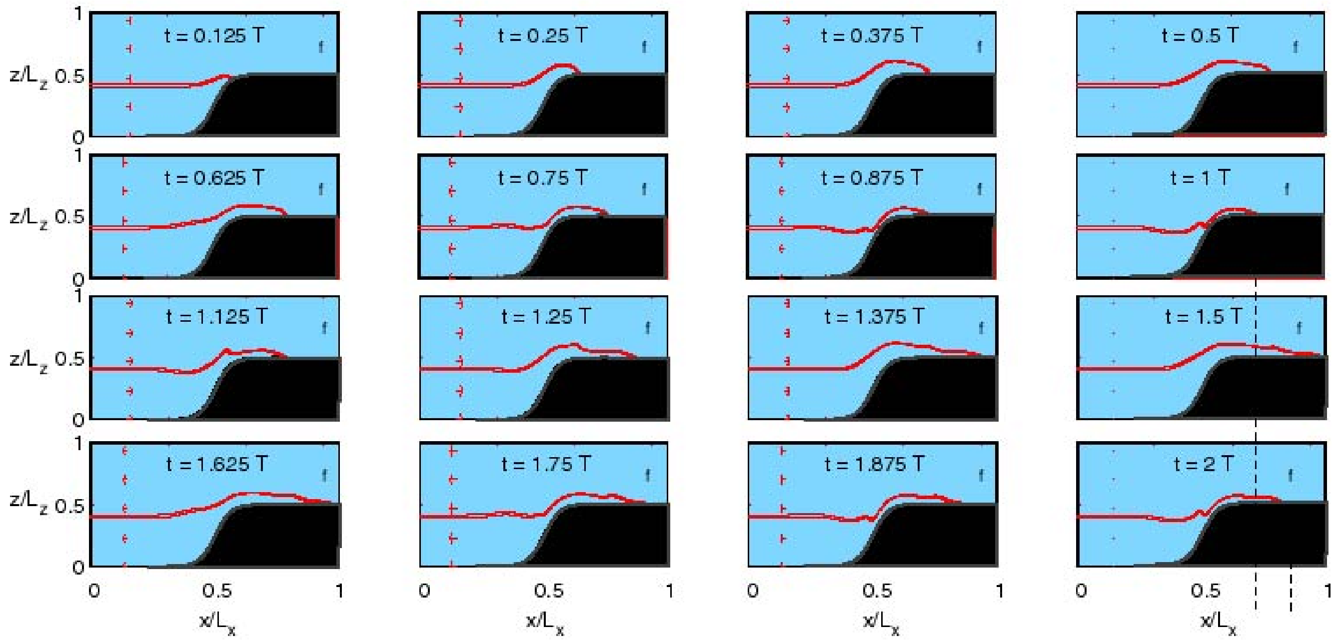

Figure 1: Bore propagation onto shelf.

Figure 2 shows the density, relative to the initial values, at approximately mid depth as a function of cross-shore position and time.

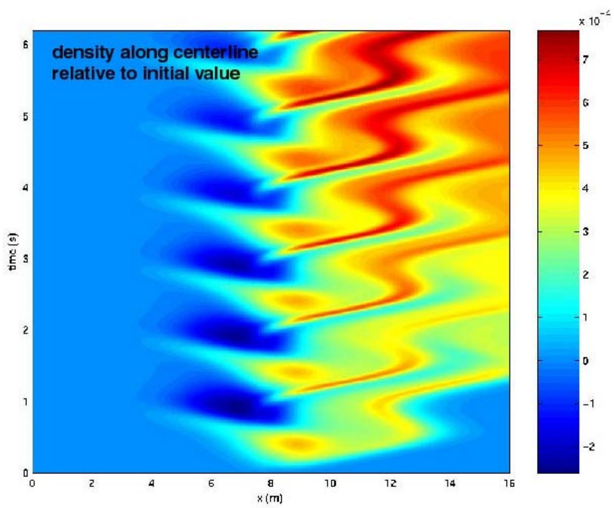

Figure 2: Density vs cross-shore x and time t.

IMPACT/APPLICATION

A quantitative understanding of the role of dissipation and mixing in exchange flows, even for idealized problems, may lead to a deeper understanding of the dynamics of naturally occurring flows, particularly those in which dissipation and mixing are clearly significant dynamical processes. Two limiting flows, for which analytical solutions exist, provide a useful framework for understanding exchange flows in which mixing is important. Both limits can be applied to the lock exchange problem in which water is exchanged between two reservoirs of differing density. The first limit applies when viscous and diffusive effects are so strong that the fluid is vertically well mixed within the connecting channel and the density gradient is therefore horizontal. The second limit is when no mixing occurs and the flow is described by classical two-layer hydraulic theory. In both limits, the lateral exchange between the reservoirs can be quantified in terms of the external parameters of the flow. Real exchange flows often exist somewhere between these limits due to finite but incomplete mixing. These flows are not well described by either limiting theory. A manuscript is in press (Hogg, Ivey and Winters, 2000) that documents the transition between these limits and the role of mixing in determining lateral scalar and volumetric transport.

The numerical tools should be generally useful for process oriented studies of topographically influenced flows. Simulations such as those shown in Figure 2 may also be useful for evaluating the effect of solitary waves in acoustic propagation in shallow water.

TRANSITIONS

The numerical model developed for this project is currently being used in several other efforts.

Andy Hogg, a Ph. D. candidate at the University of Western Australia is continuing to investigate the role of instabilities and mixing in determining volumetric and tracer transport in exchange flows through contracting channels. He is also using the code as a means for performing multidimensional stability analyses of long waves in continuously stratified, streamwise variable exchange flows.

Larry Pratt is using a modified version of the stability code to investigate wave dynamics in the Strait of Bab el Mandab.

Dr. Tim Finnigan, now at the University of Hawaii is using the numerical model to augment a laboratory study of convectively driven exchange flow over a sill.

Don Slinn and Tom Pierro are investigating unstratified turbulent flow over a rippled bottom.

Mike Coates at Deakin University is also using the code and collaborating on a laboratory-numerical investigation of wind-driven coastal upwelling.

Simulations are currently underway with Harvey Seim at the University of North Carolina as part of an NSF funded study of benthic frontogenesis.

Simulations are currently being implemented to investigate the near field dynamics as a stratified flow passes through a grid mesh. This is collaborative work with Don Delisi and Pascale Lelong at Northwest Research Associates.

PUBLICATIONS

Winters, K. B. and G. N. Ivey 1999, Turbulent properties in a wave energized benthic boundary layer on a slope, *Proceedings of the Eleventh Hawaiian Winter Workshop: Internal Waves and Topography*, University of Hawaii at Manoa, 149-154.

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Ivey, G. N., Winters, K. B. and I.P.D. De Silva 2000: Turbulent mixing in an internal wave energised benthic boundary layer on a slope. *J. Fluid Mech.* in press.

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